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LOW FREQUENCY MODES OF THE TROPICAL TROPOSPHERE

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1. INTRODUCTION

Quasi-periodic variations in tropical winds and surface pressures with periods of 40-50 days were first reported by Madden and Julian (1971). They recognized that the oscillation was a global scale phenomenon which influenced much of the tropical troposphere. Madden and Julian (1972) described the oscillation as a poleward and eastward propagating disturbance with a zonal wavenumber 1 structure which seemed to modulate the convection in the tropical Pacific. In a study of the relationship between atmospheric angular momentum and the earth's rotation rate Langley et.al. (1981) reported an oscillation with 40-50 day periods which appeared in both time series. This oscillation was determined by Anderson and Rosen (1982) to be the zonally symmetric component of the oscillation reported by Madden and Julian.

The observation of the zonally symmetric component of the 40-50 day oscillation suggested the possibility that a dynamical basis for the time scale of the motion may result from zonally symmetric dynamics rather than wave number 1 processes. This hypothesis was offered additional support by Goswami and Shukla in a recent work where they observed similar slow oscillations in a non-linear zonally symmetric general circulation model.

In order to examine this idea it is necessary to develop an understanding of the linear symmetric modes of the tropical atmosphere. To adequately describe these modes it is necessary to use a basic state which includes the effects of the tropical Hadley circulation. When these effects are included a new set of low frequency modes are produced, the slowest of which has a similar time scale to and shares many structural similarities with the observed oscillation. These new modes are the motions which result when the geostrophic modes of a resting basic state are modified by the Hadley cell.

2. THE MODEL

For experimental simplicity the model domain was chosen to be an equatorial beta-plane with absorbing walls located at 30°N and 30°S latitude. The Hadley cell basic state for the

model is determined by running a non-linear forced model to equilibrium with forcing consisting of representations of cumulus heating near the equator and radiative cooling away from the equator. The heating magnitude was chosen to give agreement with observed values of the large scale vertical velocity field. The model is based on zonally symmetric hydrostatic primitive equations (1) with the inclusion of damping designed to represent the effects of surface friction and non-symmetric eddy fluxes of momentum. The numerical formulation of the model uses a finite difference vertical representation and Fourier basis functions in the horizontal.

$$\frac{Du}{Dt} = fv - \alpha(y, z)u \quad (1.1)$$

$$\frac{Dv}{Dt} = -fu - \alpha(y, z)v - \frac{1}{\rho} \frac{\partial p}{\partial y} \quad (1.2)$$

$$\frac{D\theta}{Dt} = Q(y, z) - \gamma(y, z)\theta \quad (1.3)$$

$$\frac{\partial(\rho w)}{\partial z} = -\frac{\partial(\rho v)}{\partial y} \quad (1.4)$$

$$\frac{\partial p}{\partial z} = -g\rho \quad (1.5)$$

$$\text{where } \frac{D}{Dt} = \frac{\partial}{\partial t} + v \frac{\partial}{\partial y} + w \frac{\partial}{\partial z}$$

When run to equilibrium the model produces a reasonable simulation of the observed Hadley cell. Plots of the simulated wind fields are given as figure 1. In the real atmosphere, of course, the westerly jet extends further northward due to the eddy convergence of momentum but the interior of the simulated circulation should be adequate for studies of the equatorial motions.

The next step in the determination of the linear normal modes is the generation of a linear perturbation model from this basic state. Once this is done the eigenmodes of the model can then in principle be found as a matrix eigenvalue problem. In practice, since the model equations are not separable into horizontal and vertical structure equations, the

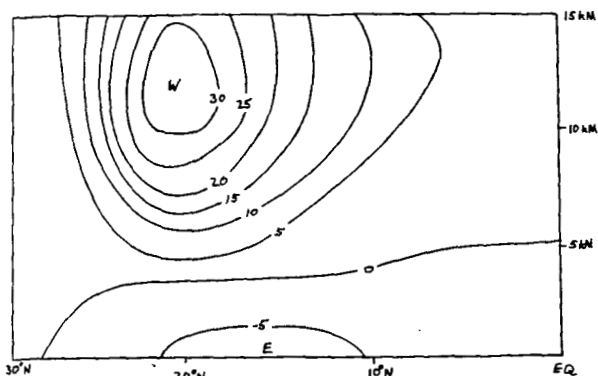


Fig. 1a. Model basic state zonal winds (m/sec).

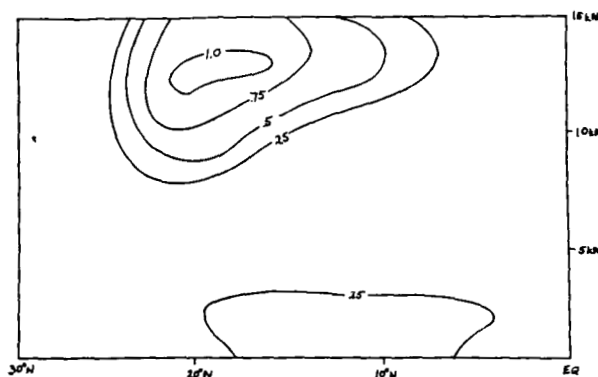


Fig. 2a. Slow model mode zonal wind amplitude. Units arbitrary.

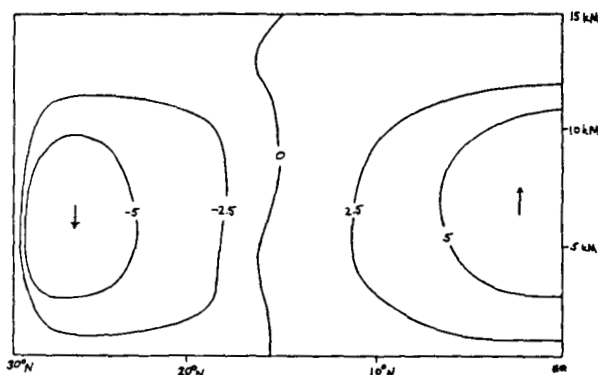


Fig. 1b. Model basic state vertical winds (mm/sec).

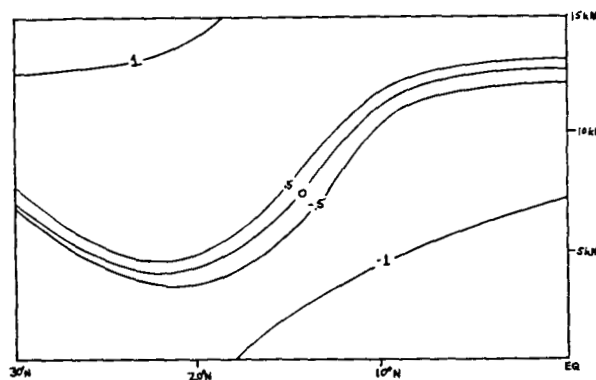


Fig. 2b. Slow model mode zonal wind phase/pi.

order of this eigenvalue problem is much too large for direct solution. It is however possible to avoid this difficulty if one is only interested in the slowest modes of the model. To determine the slow modes a prognostic version of the linear model is stepped forward in time and a representative time series is saved. This time series is then low pass filtered and a complex exponential representation is fit to it using a process known as Prony parameter estimation. This fit provides a good approximation to the complex frequencies of the slowest modes which can then be used to construct a description of the associated spatial structure. Using this procedure it was determined that the slowest oscillating model mode has a period of 30.1 days and an equatorially symmetric spatial structure which is given as figure 2. The spatial structure of the mode can be described as being very similar to the effects of an oscillation of the Hadley cell amplitude.

3. CONCLUSION

A representation of the observed spatial structure of the oscillation zonal wind field is reproduced as figure 3 from Anderson and Rosen (1982). This representation is based on an amplitude-phase extension of the principal component or empirical orthogonal function technique and can be directly compared with the

model fields. The amplitude fields are in good agreement with both fields showing a well developed maximum on the southern edge of the jet. The phase features do not agree as well although both fields show a tendency for poleward phase propagation. The difference between the observed and model phase fields may very well result from the lack of a model parameterization for momentum transport by cumulus clouds.

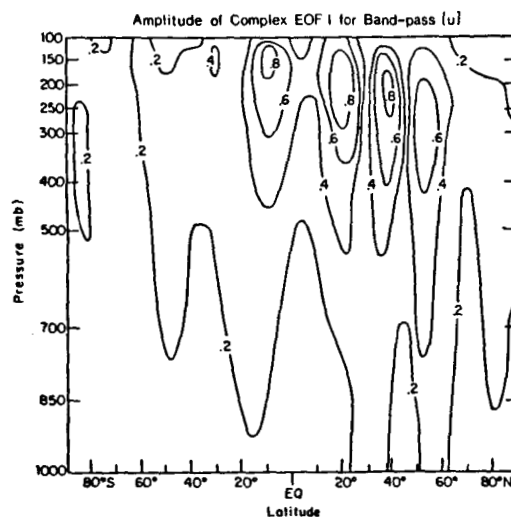


Fig. 3a. Observed oscillation amplitude. Units arbitrary.

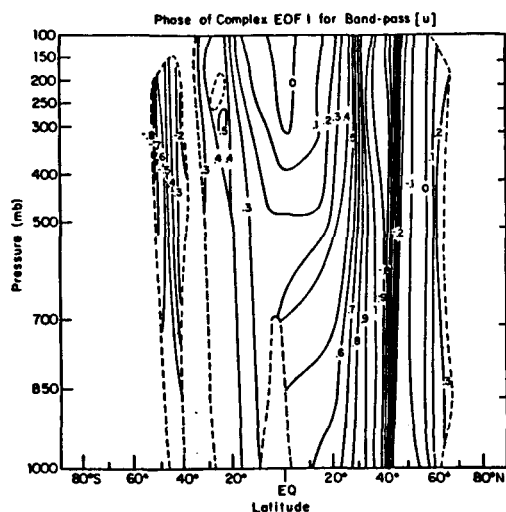


Fig. 3b. Observed oscillation phase/ π .

In conclusion this work examines a new class of slow equatorial wavelike motions which provide a possible explanation for the observed low frequency motions in the tropical troposphere. Many additional physical effects need to be studied; the most important of these is the effect of cumulus clouds on the linear modes. In addition more observational and modeling work is needed to define the relationship between the symmetric and zonal wavenumber 1 components of the oscillation.

4. ACKNOWLEDGMENTS

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